Integrating Harvest Plans Across Forest Cover Types: AnAnalysis of Crow Wing County Managed Timberland

by

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Technical Report
Interagency Information Cooperative

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Summary

Crow Wing County (CWC) manages approximately 70,000 acres of forest land. Economic returns from managing those lands are important to the county, as is sustaining a healthy and productive forest. Well over half of the CWC-managed lands are in the aspen forest cover type. Unlike most if not all other public forests in Minnesota, CWC-managed lands have an imbalanced age class distribution with more acres of young aspen. The CWC Land Department is concerned about upcoming declines in aspen harvesting and whether forest-wide harvest levels and revenues can be maintained by cutting heavier in other forest types. This study used a harvest scheduling model to examine opportunities to coordinate management across cover types. Findings include:

1. The potential to cover the upcoming shortfall of financially mature aspen stands depends heavily on the minimum rotation age assumed for the aspen cover type. Assuming a minimum rotation age of 40 years on all but the lowest quality aspen sites has the potential to help overcome a potential shortfall substantially. Based on current stumpage prices received by the county, if the minimum rotation for aspen is assumed to be 50 years, substantial shortfalls in revenue seem likely for approximately 15 years starting relatively soon.

2. The estimated net present worth from timber harvesting returns is sensitive to the minimum rotation age assumed for aspen. Results suggest that increasing the minimum rotation age from 40 years to 50 years would cost an estimated $1.8 million dollars in lost timber revenues regardless of whether area control and revenue control constraints are used.

3. The cost of imposing forest regulation constraints to balance both revenue flows and area harvested, comes at an estimated cost of approximated $2.2 million. This estimated cost varied relatively little over the range of minimum rotation ages assumed for aspen (40 to 50 years).

4. Relaxing the area and revenue control constraints to allow for small deviations in flows over time has the potential to help reduce costs of even flow constraints from approximately $2.2 million to $1.4 million for the two cases examined that relaxed the regulation constraints.

5. Stands in the oak cover type are currently old with relatively few stands currently younger than age 70. It seems unrealistic to assume that many of these older stands can be held another 60 to 80 years so that a fully regulated condition can be created by the end of the 100-year planning horizon. However, during the next 100 years regulation constraints can help move the oak type towards regulation so that most if not all 5-year age classes are represented in the forest.

6. The oak type can likely play an important role in overcoming any short-term shortfall in timber revenues. However, it is important to note that the aspen age class imbalance is

apt to be somewhat cyclical with it likely impossible to hold a large portion of the oak type to help cover any future aspen shortfall.

7. The red pine cover type is more important than its relatively small area (approximately 2800 acres) might suggest. Growth rates for red pine stands are generally double that of aspen stands as are current red pine saw log stumpage prices compared to aspen stumpage prices.

8. In terms of the area harvested each year, the aspen cover type makes up 80% or more of the harvest. But the aspen cover type contains a mix of species. For the forest as a whole, the amount of the aspen product type is projected to vary over time. It is generally at least 50% of the timber revenue.

9. Results suggest that CWC cannot maintain current timber revenue stream indefinitely at current timber prices. However, using a 40-year minimum rotation for the aspen cover type, current revenue streams can be maintained for nearly 35 years. Impacts of imbalances in aspen age class will likely surface again in the future, likely at a time when the forest has less mature oak. It is important to note that timber prices used for the analyses are recent prices received by the county and relatively low compared to prices over the last 20 years. And long-term shortfalls are not large, approximately $50,000 per year compared to current stumpage revenues of approximately $600,000 per year.

10. Future analyses should correct for an approximate 500 acres of reserved acres that were considered harvestable in all analyses. Future analyses might also consider the estimated administration cost of timber sales in more detail, especially for small stands. These changes would almost certainly have minimal impact on overall results from a forest-wide strategic standpoint. However, it is important to recognize these shortcomings when considering operational aspects of the results. The modeling process was detailed in that resulting management schedules can easily be linked and mapped with the county's current GIS software.

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Introduction

This paper summarizes work by the University of Minnesota, Interagency Information Cooperative (IIC) to help support the forest planning process of the Crow Wing County (CWC) Land Department. It describes results of analyses developed to assist the Land Department. Key forest management assumptions are varied between analyses to help learn about alternative management strategies for CWC lands. Emphasis is on coordinating management across forest cover types, going beyond traditional forest regulation methods generally referred to as "area control" methods that are often applied to each forest cover type separately (Davis and Johnson 1987).

The CWC Land Department manages approximately 70,000 acres of forest land with 40,000 acres of forest land in the aspen cover type. The aspen cover type is the largest forest cover type by far (Figure 1). With much of the forest land tax forfeited lands, the majority of the forest area is in upland forest cover types. The aspen forest cover type can be harvested on a shorter rotation than most other types, making it possible, on average, to cut a higher percentage of this cover type annually. However, CWC has cut the aspen forest cover type heavily over the last 25 years, as 25 years ago the age class distribution of this cover type was dominated by older stands that had high tree mortality—CWC could not easily save or store the old aspen for later harvest. Today, CWC's aspen cover type has relatively few acres that will be financial maturity in the next 10 to 15 years. This is quite atypical in terms of situations faced today by other public forest land management agencies in Minnesota. Furthermore, the CWC Land Department depends heavily on returns from timber sales to cover its operating expenses. Aspen is one of higher-valued tree species in Minnesota. Key planning questions for CWC concern the potential to harvest more from other forest cover types in the short term to help sustain revenues needed to support all management operations of the Land Department. Recent downturns in timber prices in Minnesota for most all tree species, have added to concerns about short-term timber revenues.

As summarized above, the current stand age class distribution for the aspen cover type shows that a less than desirable number of acres will reach economic maturity over the next 10 to 15 years (Figure 2). The degree of imbalance depends on the minimum rotation age assumed for the aspen cover type. Specifically, the aspen cover type currently has relatively few acres in stands older than age 30. These age 30+ stands represent all the older acres that will be harvestable in the aspen cover type during the next 20 years if age 50 is the minimum rotation age used for the aspen cover type. However, if the minimum rotation is 40 years then those stands would be all of the harvestable stands in the aspen type for only the next 10 years. In other words, the minimum rotation age for aspen influences the length of time until the 4000+ acres in the 26 to 30 year age class and the 6000 acres in the 21 to 25 year age class (Figure 2) will become available for harvest.

The current stand age class distribution for the oak forest cover type (Figure 3) is quite imbalanced with most acres currently financially mature. More harvesting of the oak cover type in the next 10 to 20 years could potentially complement the expected reduction of harvesting of the aspen cover type. As shown earlier, oak is the second largest cover type in CWC (Figure 1), with far more acres than the third largest forest cover type and far fewer acres than the aspen cover forest type.

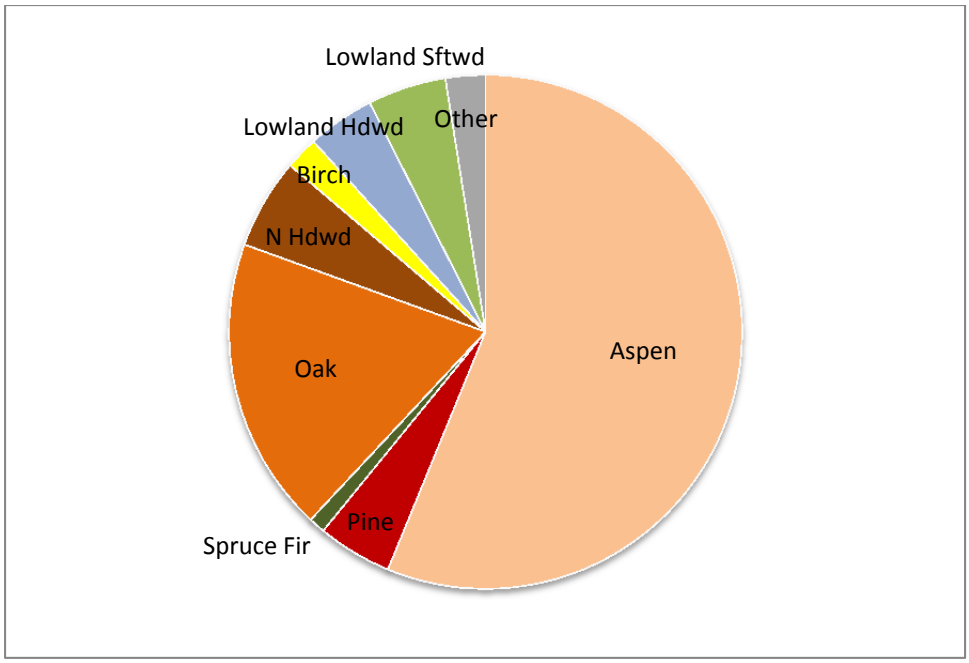

Figure 1. Distribution of Crow Wing County forest land by forest cover type.

Aspen Initial

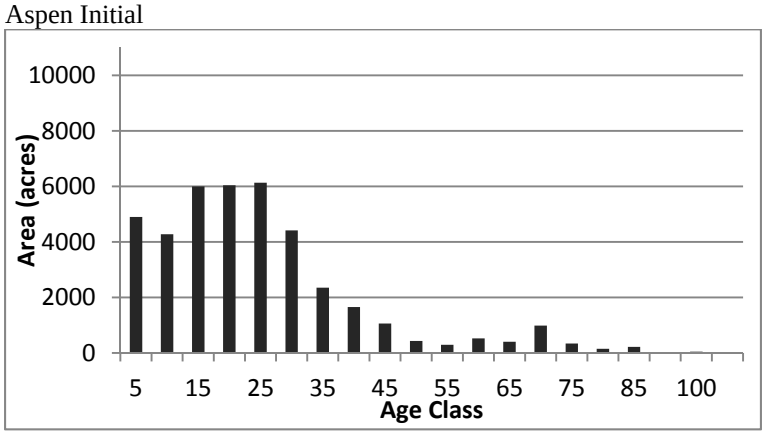

Figure 2. Initial stand age class distribution of the aspen forest cover type. Age class labels indicate the oldest stand age in each 5-year age class.

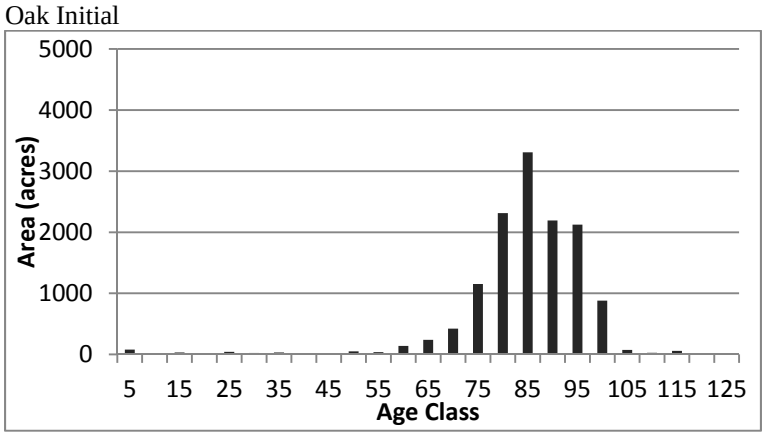

Figure 3. Initial stand age class distribution of the oak forest cover type. Age class labels indicate the oldest stand in each 5-year age class.

Traditionally, public forest land management agencies have relied on simple formulas or computer simulation models to help set forest-wide harvest levels. Such approaches assume that priorities for sequencing stands for harvesting are known. They basically project (simulate) forest conditions forward through time based on the assumed priority for sequencing stands for harvest. Typically, this has been done separately for each forest cover type. In contrast, computer optimization models make it possible to explore management options in greater detail. Priorities for sequencing stands for harvest need not be specified *apriori* and most if not all cover types can be considered at the same time. Identifying harvest timings and management intensity can be an output of an optimization analysis. Optimization models can search through an almost limitless numbers of possible forest-wide management combinations of possible stand-level options to help find "best" solutions. Best is defined by the user through a specified objective function. For modeling purposes in this study, the objective is assumed to be to maximize net discounted returns from timber sales (4% annual interest rate) subject to a set of overriding forest management constraints that define CWC forest management policies. Multiple scenarios are analyzed to help estimate and compare impacts of alternative forest management policies and strategies.

Methods

An updated version of Dualplan (Hoganson and Rose 1984; Hoganson and Reese 2011) was used for the harvest scheduling analyses. The basic modeling units (analysis areas) recognized were 69,671 acres (3667 individual stands) from CWC's stand-level inventory. Modeling results can be linked back to stand level data for potential use in plan implementation. As with many county inventories in Minnesota, much of the CWC inventory is relatively old. Because of the age of the data, only the forest cover type, stand age, and site index estimates were considered reliable at the stand level. Typically, one would also like to recognize stand-level information on species mix and stocking (basal area), but that was not feasible with the available data.

The only management costs recognized were costs associated with sale administration. Sale administration costs were assumed relatively low, as it was assumed that most admin costs could

be covered with current county staffing without additional funding. Sale administration costs can still make some low-volume stands nonmarketable, especially if a stand is small in area and contains low-valued products. Compared to end-of-rotation sale administration costs, administration costs for thinnings and partial harvests were assumed to be $20/acre higher for all thinnings and partial harvests. Recent CWC stumpage prices were used for estimating the net present value of each timber harvest option for each stand. Stumpage prices were assumed to remain constant over time. Estimates of stumpage price were $20/cord for aspen, $11 to $17/cord for oak depending on estimated site quality, $10/cord for other hardwoods, $16/cord for spruce and balsam fir in upland cover types, $7/cord for pine pulp and tamarack pulp and spruce and fir in lowland cover types, $40/cord for red pine saw logs and $30/cord for jack pine saw logs. Five-year planning periods were used for tracking all management activities over a 100-year planning horizon. Net present value estimates were based on a 4% interest rate.

Most growth and yield estimates were based on empirical yield tables developed using recent FIA inventory data along with short-term projections of that data using growth model projections developed for a 2006 Environmental Impact Statement for a recently proposed mill expansion in northern Minnesota (MN DNR, 2006). The yield estimates are based on plots located in 15 northern Minnesota counties. In developing the tables, data was weighted based on the length of the growth projection, with longer projection lengths receiving less weight. No growth projections were used that projected stand growth for more than 19 years. For the aspen forest cover type, volume estimates were lowered for stands over age 65 to better account for expected losses from tree mortality, as tree mortality estimates were questionable for the growth model used. Table 1 shows total volume estimates by age for the aspen cover type for a range of site index levels.

Table 1. Average volume yield (all species) by site index and stand age for the aspen cover type (cords/acre). These estimates were reduced in analyses to recognize site level guidelines for leaving residual trees after harvest.

Age (years)	Site Index								
	45	50	55	60	65	70	75	80	85
40	8.2	10.9	13.5	16.2	18.9	21.4	23.9	26.4	28.9
45	9.3	12.3	15.2	18.1	21.0	23.6	26.3	28.9	31.5
50	10.7	13.7	16.8	19.8	22.8	25.7	28.6	31.5	34.3
55	12.2	15.2	18.3	21.4	24.4	27.6	30.8	33.9	37.1
60	13.8	16.8	19.8	22.9	25.9	29.4	32.9	36.3	39.8
65	15.3	18.4	21.5	24.6	27.7	31.3	34.9	38.6	42.2
70	13.6	16.3	19.1	21.8	24.6	27.8	31.1	34.3	37.5
75	11.9	14.3	16.7	19.1	21.5	24.3	27.2	30.0	32.9
80	10.2	12.2	14.3	16.4	18.4	20.9	23.3	25.7	28.2
85	8.5	10.2	11.9	13.6	15.4	17.4	19.4	21.4	23.5
90	6.8	8.2	9.5	10.9	12.3	13.9	15.5	17.2	18.8

All scenarios analyzed used statewide voluntary site-level forest management guidelines assuming 40 square feet of basal area of merchantable timber would be retained onsite for portions of the stand within riparian areas and 4 square feet of basal area left onsite for areas outside of riparian areas. Specific tree species left as residuals were pro-rated based on species basal area estimates. A water resources map for the county was used within a GIS analysis to

estimate the percent of each stand that is within a riparian area. Roughly 2100 of the 69,700 acres modeled had 10% or more of the stand within a riparian area.

Partial cut entries were considered for the oak cover type. First entries were targeted for a first entry at age 50 followed by a partial harvest at age 80 (or later), leaving a residual basal area of 70 square feet to be followed by a final harvest 20 years later. Few oak stands are currently younger than age 50 so for the initial rotation for most oak stands only two stand entries were considered. Rotation ages for the oak cover type ranged from 100 years to 165 years. This assumption was somewhat limiting for final harvesting oak in some later planning periods because much of the oak cover type is already 80 years old at the start of the planning horizon and will be beyond age 165 before the end of the planning horizon (Figure 3).

Thinning options were considered for red pine plantations. Yield data for thinning were developed using the Resinosa model (Mack and Burk 2002, 2004, 2005). Most of these options used a 20-year interval between thins. With red pine a valuable product and the number of plausible thinning strategies large, this is one facet of the problem deserving of more attention in future analyses. Thinning options were not considered for stands in the red pine cover type that were not classified as plantations.

Approximately 500 acres of reserve areas were identified in the CWC stand inventory. No harvesting was allowed in reserve areas but reserve areas were tracked to help address forest condition estimates over time.

Modeling did not consider opportunities to change forest cover types for future rotations. An ecological map layer was available and linked to stands for reporting outputs. That map layer was also used in estimating the quality/value of oak in stands in the oak forest cover type. Relative price differences assumed for oak quality were small, ranging from $11 to $17 per cord.

Scenarios

Multiple runs of the forest management scheduling model were used to help better understand the forest management situation facing CWC. Alternative management strategies were examined via a set of future scenarios where each scenario was modeled with results used for comparing scenarios. For each scenario, it was assumed that the objective of management was to maximize the net present value (NPV) of the forest over an infinite planning horizon. Initially, a set of three benchmark scenarios were developed that varied only in terms of the minimum rotation age assumed for the aspen cover type—minimum rotation lengths of 40, 45, or 50 years. These benchmark scenarios are used to help better understand timber harvesting potentials and the current age class imbalances over all forest cover types. Constraints were included in all other scenarios to help address the current age class imbalances. Most of these constraints are forest regulation constraints, offering a means for moving a forest cover type more toward a regulated condition—a condition having a more balanced age class distribution which is well-suited for sustaining timber harvesting and desired forest conditions.

In addition to the three benchmark scenarios, five additional scenarios were also modeled in detail. CWC foresters were instrumental in helping define these scenarios and in providing details on the information needed from their most recent forest inventory. Of these five scenarios, just like with the three benchmark scenarios, three scenarios varied only in terms of the minimum rotation age assumed for the aspen forest cover type. Unlike the benchmark runs, these three scenarios included forest regulation constraints. The phrase "Area & Revenue Control" is included in their names reflecting the type of forest regulation constraints assumed. Technically, strict area control will create a regulated forest in *r* years where *r* is the rotation length in years. Strict area control cuts an equal number of acres each year. However, this cutting is not always possible during some planning periods when a minimum rotation age for harvesting is also imposed. For all three of the "Area & Revenue Control" scenarios, area control constraints were included to limit the maximum area that could be cut in each period. Specific levels for these maximum area harvest limits varied for the aspen cover type and were calculated for the aspen type by estimating the area that would be harvested each 5-year period if the cover type was fully regulated based on the minimum rotation age assumed for aspen. Less harvesting than this maximum was allowed, as it was recognized that less harvesting would likely be needed for some early periods because of the imbalanced age class distribution for the aspen forest cover type initially.

Revenue control limits were also included in the "Area & Revenue Control" scenarios. Specifically, average stumpage revenue was capped at $600,000 annually for each 5-year planning period with the intent that the cap would force the model to hold timber in order to sustain timber revenues over time. These constraints were much like volume control constraints where species volumes are weighted by timber prices to reflect differences in timber values. Periodic timber revenues were allowed to be less than the cap level, as it was expected that these levels may not be achievable every period because of the imbalanced age class distributions initially.

Two additional scenarios were developed where the constraints in each of two "Area & Revenue Control" scenarios were relaxed. These scenarios are named "Area & Revenue Ranges" with an added number that reflects the minimum rotation age assumed for the aspen forest cover type. In these two "range" scenarios, rather than assume revenue needed to be at least $600,000 annually in each period, the constraints were relaxed allowing annual revenue to range between $560,000 and $640,000 for each planning period. The two range scenarios differed only in the assumed minimum rotation age for aspen—either 40 or 45 years. The nomenclature is simplified and a little misleading in that the minimum rotation age for the aspen type for its lowest site quality class was not lowered below 45 years for any "Age 40" scenario. Table 2 summarizes the differences in the five scenarios that included forest regulation constraints

The benchmark scenarios contained no forest-wide constraints. The benchmark scenarios do constrain the solution only in terms of the maximum and minimum rotation lengths considered for each stand. These stand-level limits are based on the stand's forest cover type. In a modeling sense, these were not constraints - the rotation age limits just defined the choices to consider for each stand type. All of the scenarios considered beyond the benchmark shared some common constraints that did not vary by scenario. Specifically, constraints were included for each period defining the maximum total area treated (1900 acres) and the total area final (regeneration)

harvested (1,500 acres). Forest regulation constraints were also included to limit the maximum area regeneration harvested each period for each of the major cover types—red pine (125 acres), northern hardwoods (200 acres), birch (300 acres), lowland hardwoods (100 acres), and ash (250 acres). All scenarios targeted retaining at least 800 acres of aspen between ages 40 to 70 through the first four planning periods and 1,000 acres for all periods beyond period 4. Constraints were also included to target at least 1,000 acres of the oak type in the age 70 to 140 range and 200 acres of red pine in the age 85- to 125-year range.

Table 2. Summary of the five scenarios that used forest regulation constraints.

Description of Limits	Aspen 40 Area & Revenue Control	Aspen 45 Area & Revenue Control	Aspen 50 Area & Revenue Control	Aspen 40 Area & Revenue Ranges	Aspen 45 Area & Revenue Ranges
Low SI Aspen -- Min Rotation age	45	45	50	45	45
Med SI Aspen -- Min Rotation age	40	45	50	40	45
High SI Aspen -- Min Rotation age	40	45	50	40	
Aspen Acres: Age 0-5 Min/period					
Periods 1-4 (years 2012-2032)	no limit	no limit	no limit	3500	3500
Periods 5-20 (years 2032-2132)	no limit	no limit	no limit	4000	4000
Aspen Acres: Age 0-5 Max/period	5000	4445	4000	5500	5500
Oak Acres: Age 0-5 Min/period	no limit	no limit	no limit	300	300
Oak Acres: Age 0-5 Max/period	650	650	650	2000	2000
Stumpage Revenue Min/Yr	no limit	no limit	no limit	560,000	640,000
Stumpage Revenue Max/Yr	600,000	600,000	600,000	640,000	640,000

Results

This section provides an overview of the modeling results in terms of the overall net present value of the management schedules developed and the associated age class distributions of the aspen and oak forest cover types at various points in time over the planning horizon. In developing management schedules, the model attempts to maximize NPV while emphasizing the forest regulation constraints that define the scenario. In the process, the constraints take precedence over the maximize NPV objective.

Net Present Value

All model applications used NPV as the objective function to maximize. The NPV estimates reflect returns from stumpage sales and the associated discounting impact of when those returns occur. Maximum NPV estimates differed by scenario because of the different constraints and different assumptions associated with each scenario.

Results for the Benchmark scenarios are one basis for comparison, realizing that these scenarios included no constraints for bringing the forest age class distributions to a more balanced (regulated) state or no constraints on balancing timber revenues over time. Figure 4 shows the net revenue flows by 5-year planning period for the three benchmark runs. These scenarios differ in only the minimum rotation age assumed for the aspen forest cover type. For all three scenarios, there is a large spike in revenue in period 1 followed by relatively low revenues in the next three periods and then a spike again in period 5 (year 25). The two spikes reflect substantial harvesting in the oak type using 20 years between entries of a shelterwood harvesting silvicultural system. The low revenue levels in periods 2 to 4 reflect the age class imbalance in the aspen cover type, with revenue clearly lower during these periods for scenarios with longer rotation age for the aspen cover type. These dips in revenue are clearly larger under the 50-year minimum rotation age assumption. There is also a cycle of dips over time reflecting potential similar fluctuations with future rotations. In fact in future dips the low point is even ever lower (year 60 for aspen 50-year rotation) reflecting the fact that during future dips less mature oak is present at that time. The large spikes in period 1 suggest that large amounts of financially mature stands are present and that the magnitude of the amount varies somewhat by the minimum rotation age for aspen. For comparison purposes, consider that CWC has a revenue target of approximately $600,000 annually. Basically the challenge in the short term is to hold (delay harvesting) some of that spike in the first period to increase harvest levels in periods 2 to 4 to the 600,000 level. That task appears easier for the Aspen 40 scenario, as the period 1 “surplus” is larger, the period 2 to 4 shortfall is lower and really does not involve period 4, as is the clear case for the Aspen 50-year scenario (Figure 4).

Figure 5 shows the revenue flows for the three “Area & Revenue Control” scenarios by 5-year planning period. Results strongly suggest short-term problems for sustaining the $600,000 revenue flow over the entire planning horizon. Difficulties in sustaining revenues are much more pronounced when minimum rotation ages for aspen are longer. Note (Figure 5) how with a minimum rotation age for aspen at 50 years results in large $200,000 annual shortfalls in periods 2 to4. In contrast, with a minimum rotation age of 40 years for aspen, there is not a substantial shortfall in the first 40 years and shortfalls in later periods are also not as pronounced with either of the longer rotation lengths considered.

The “Area & Revenue Ranges” scenarios set targets to sustain net revenues within the $560,000 to $640,000 per year over the entire planning horizon (Figure 6). With a 40-year rotation minimum, revenues are consistently above $600,000 for the first 30 years of the planning horizon. Some of this additional harvesting during the short term likely helps reinvigorate timber volume growth, thus helping overcome any long-term impact on outputs from harvesting above the $600,000 level during the first 30 years of the planning horizon.

Of interest is the total NPV of the various scenarios as maximized through the objective function. As must be the case because it is the least constrained, the benchmark scenario with the aspen minimum rotation age at 40 years had the highest estimated NPV. This estimate was $15.47 million. That amount can be used at a benchmark to estimate the reduction in NPV under each of the other scenarios (Figure 7). Shifting the aspen minimum rotation to 45 or 50 years reduced the unconstrained benchmark NPV estimates by $0.93 million and $1.78 million respectively. As expected, adding forest regulation constraints lowered the NPV estimates. Reductions ranged

from a $2.22 million reduction with a 40-year minimum rotation to $4.06 million with a 50-year minimum rotation. By allowing harvest area and revenue to fluctuate (the "Range" scenarios) declines in NPV were reduced to $1.41 million with a 40-year minimum rotation and to $2.34 million with a 45-year minimum rotation. And as noted above, these two scenarios were better able to sustain stable revenue flows over the entire 100-year planning horizon.

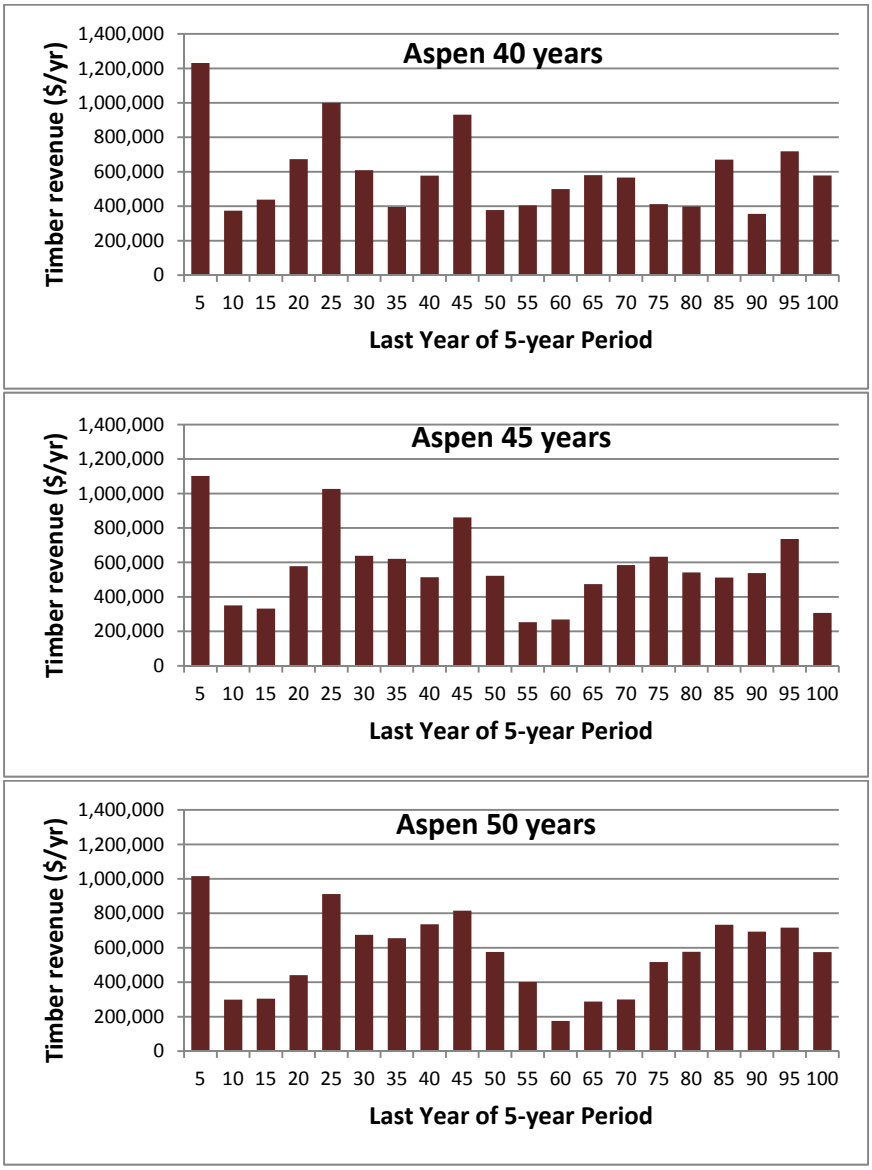

Figure 4. Revenue by period for each of the three benchmark scenarios. The Benchmark scenarios did not constrain timber harvesting and varied only in the assumed minimum rotation age (40, 45, or 50 years) for the aspen forest cover type.

It is important to note that NPV estimates are simplified. Modeled NPV estimates from timber production are based only in terms of revenue generated from stumpage sales and assumed sale administration costs. These NPV estimates are just part of the overall market benefits. Timber production supports employment throughout the local economy, with considerable value added

through forest products produced by local industry. Forest industries are large components of the regional tax base. There is clearly a multiplier effect from timber production that is not captured in the simple timber NPV estimates of this study.

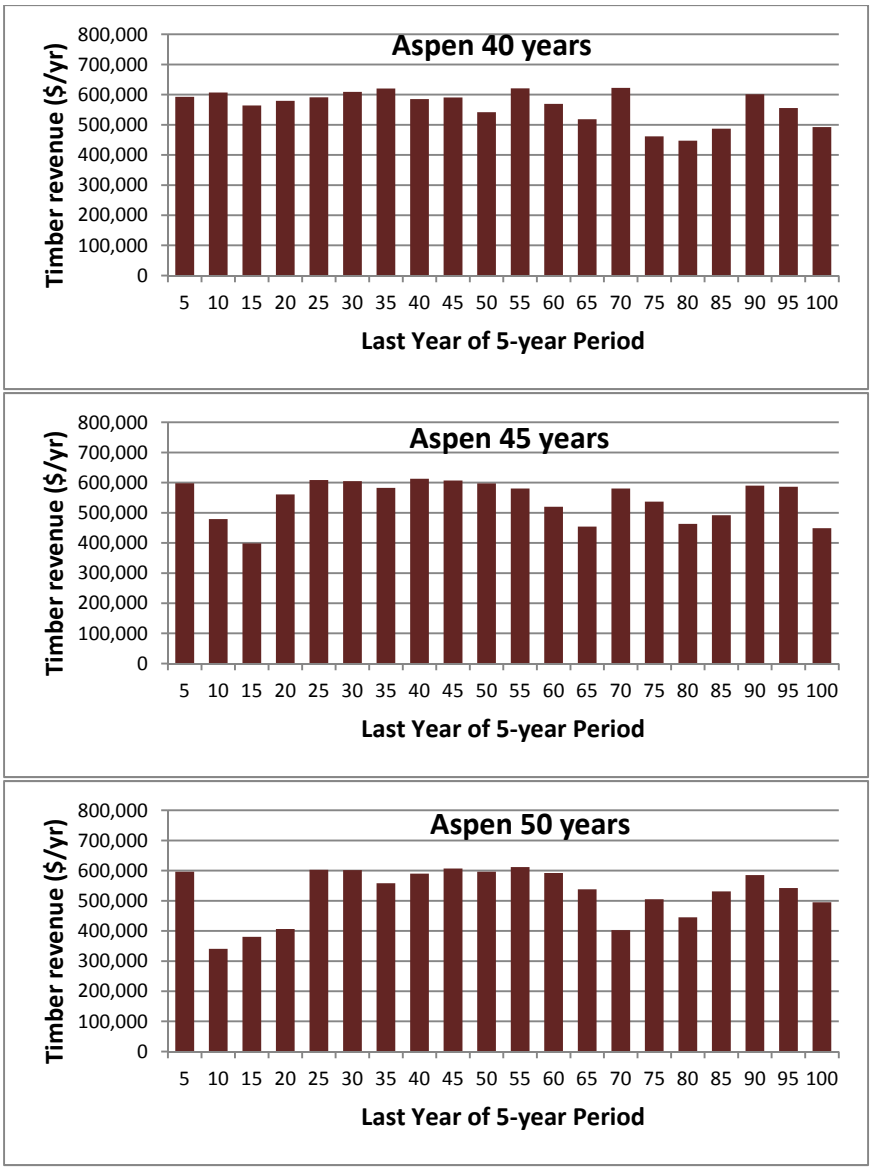

Figure 5. Revenue by period for each of the three scenarios targeting constant timber and revenue flows. Scenarios differed in the assumed minimum rotation age for the aspen forest cover type (40, 45, or 50 years).

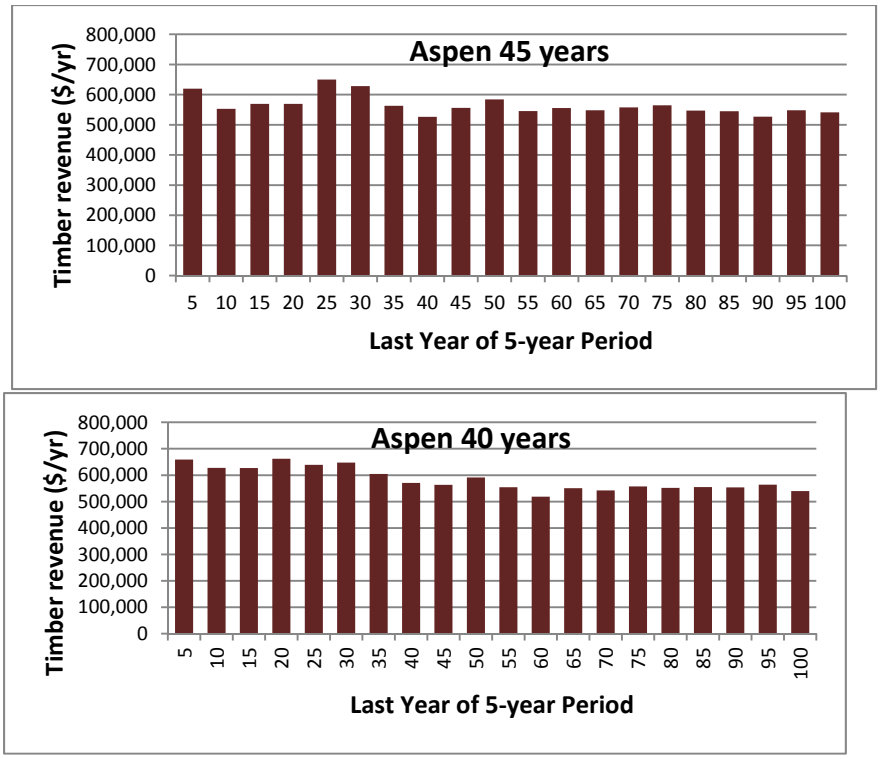

Figure 6. Revenue by period for the two scenarios that set a range on revenue flows by period. Scenarios differed in the assumed minimum rotation age for the aspen forest cover type (40 or 45 years).

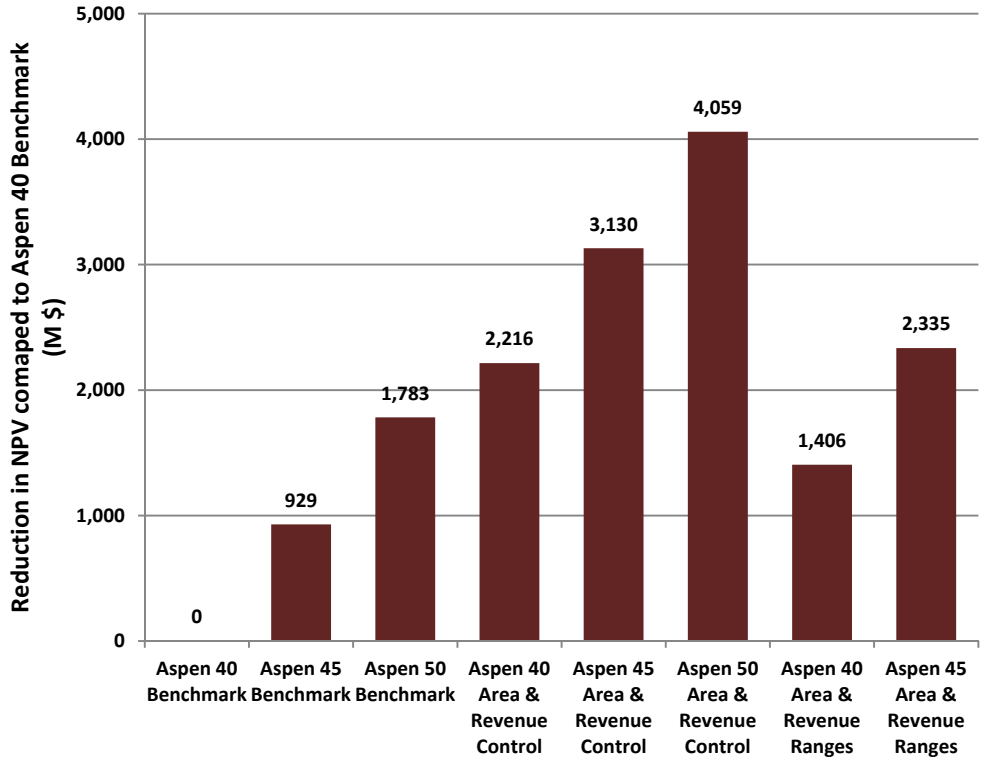

Figure 7. Reduction in total net present value (NPV) as compared to the benchmark scenario with a 40-year minimum rotation age for aspen. That scenario had a total NPV estimate of $15.47 million, the highest total NPV of all scenarios.

Age Class Distributions of the Aspen Cover Type

Figure 2 showed the initial (year 0) age class distribution for the aspen forest cover type. Initially, there are relatively few acres more than age 40. Figure 8 shows the age class distribution for the aspen forest cover type at 10-year intervals over the first 60 years of the planning horizon for the Age 40 Area and Revenue Control Scenario. The aspen forest cover type, if regulated on a 40-year rotation, would have approximately 5,000 acres in each 5-year age class. The area in the youngest 5-year age class at any point in time reflects the amount of harvesting in the aspen cover type during the last 5 years—with simplifying assumptions for the modeling, acres in the youngest age class of aspen result only from harvesting stands in the aspen cover type. So the year 10 distribution (Figure 8) shows that less than 4,000 acres of the aspen type was harvested in period 1 and period 2. The nearly 6,000 acres in the 21 to 25, 26 to 30, and 31 to 35-year age classes reflect substantially higher harvesting 21 to 35 years prior to year10. In the year 20 graph (Figure 8), all age classes from year 10 (Figure 8) have aged 10 years with some acres entering the youngest two 5-year age classes between year 10 and year 20. The approximate 5,000 acres in the youngest age class at year 20 reflects the fact that 5,000 acres of mature aspen were old enough for harvest during years 16 to 20. The year 30, year 40, and year 50 graphs show this same pattern of cutting 5,000 acres in each 5-year period. The year 60 distribution shows a small problem in that harvests in years 51 to 55 dropped to less than 4,000 acres, basically a result of requiring some older aspen while still allowing 5,000 acres to be harvested each year. Had the allowable cut been set to 4,875 acres rather than 5,000 acres this reduction in years 51 to 55 would not have occurred. Although aspen harvesting was lower in the year 51 to 55 period, annual net revenue for the period was still slightly above $600,000 (Figure 5).

Figure 9 shows the age class distributions over time for the Age 50, Area-and-Revenue Control Scenario. Under this scenario, the targeted harvest area is approximately 4000 acres, dividing the 40,000 acres of the aspen type into ten 5-year age classes. However, the graphs show that this is a problem because of the lack of acres age 50 or older during the early periods of the planning horizon. The graph for year 20 (Figure 9) shows far fewer acres harvested from the aspen type during the first three 5-year periods. This is clearly because of the longer range assumed for the aspen type under this scenario. As seen in graphs for year 30, year 40, year 50 and year 60 (Figure 9), there is not a problem harvesting 4,000 acres /period in periods beyond year 20.

Figure 10 shows the age class distributions for the “Age 40, Area-and-Revenue Ranges” Scenario. The acres harvested each period fluctuate yet generally stay within the 4,000 to 5,500 acre range as specified for all planning periods. The age class distribution appears quite balanced relatively early in the planning horizon, yet not ever that of a fully regulated forest with equal area in each age class.

Figure 11 shows the age class distributions for the “Age 45 Area-and-Revenue Ranges” Scenario. This scenario can harvest only between 2,000 to 3,000 acres in the first 15 years because of the limited amount of age 45 or older aspen available in early periods. To help understand, note how the approximate 2,200 acres in the age 45 age class in year 10 are harvested to become the approximate 2,200 acres in the age 10 age class in year 20. By year 20

there are 6000 acres in the year 45 age class so harvesting at least 4000 acres is no longer a problem after year 20.

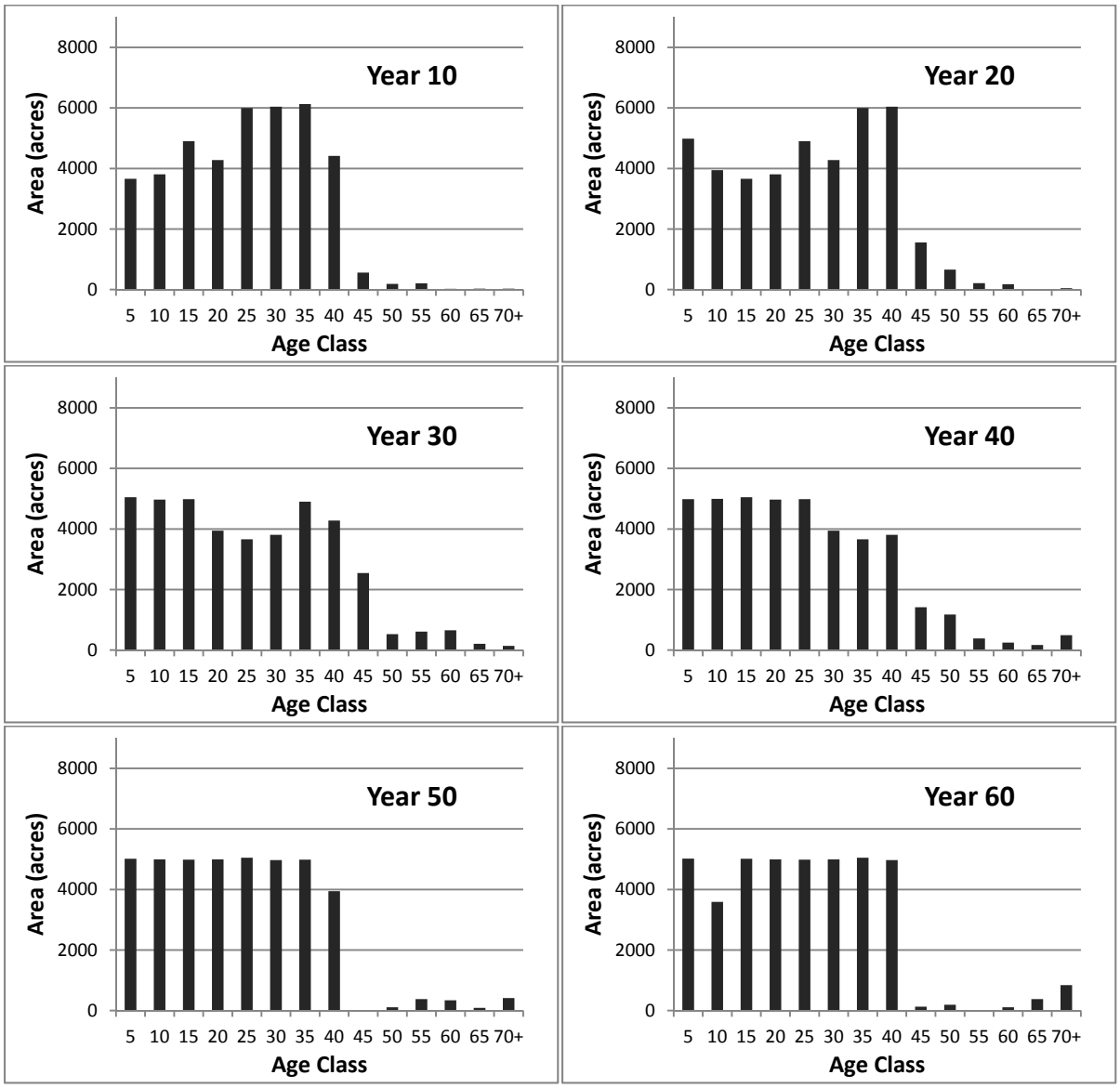

Figure 8. Projected age class distributions for the aspen cover type at 10-year intervals for the "Aspen40, Area-and-Revenue Control" Scenario.

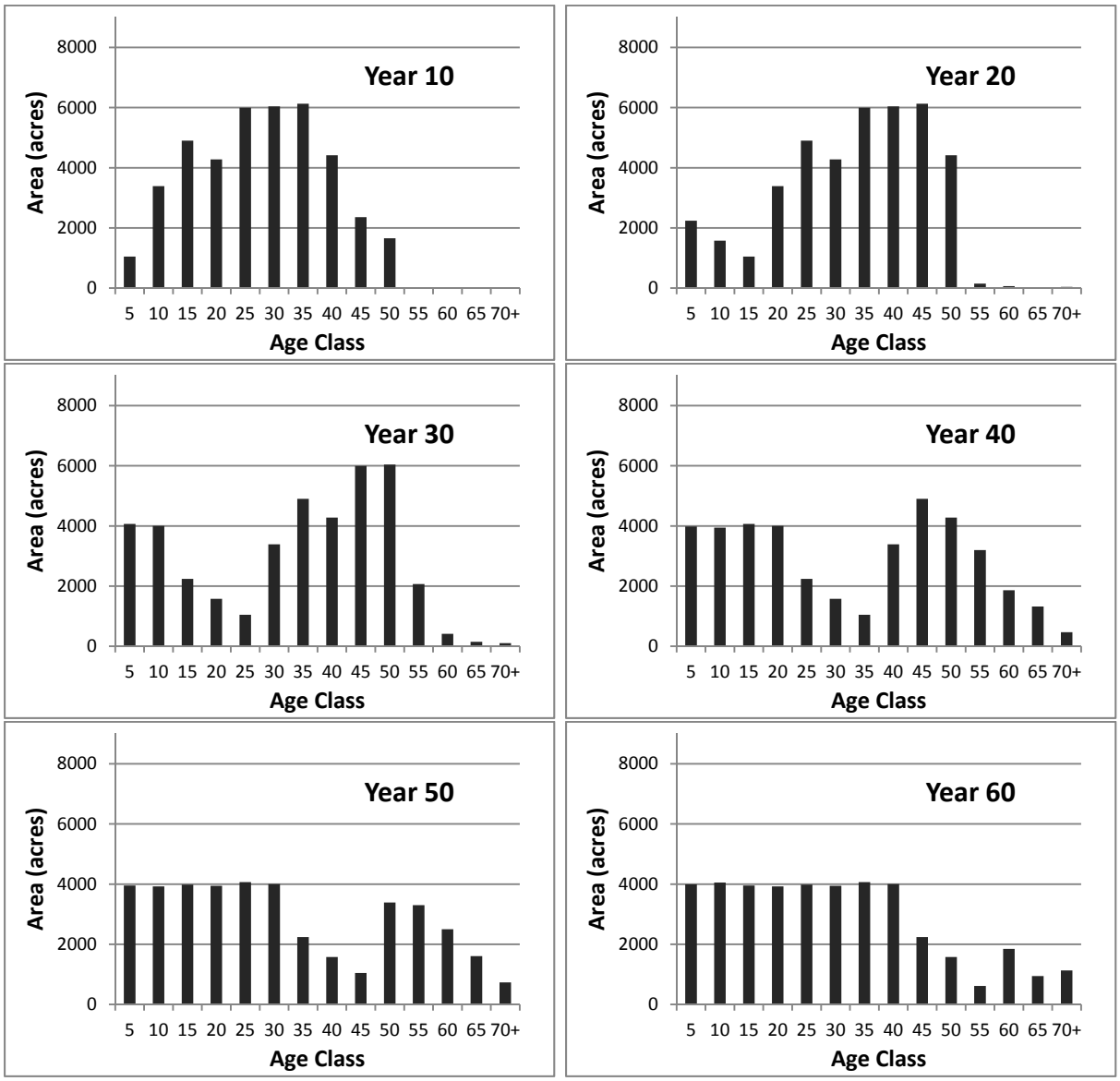

Figure 9. Projected age class distributions for the aspen cover type at 10-year intervals for the "Aspen50, Area-and-Revenue Control" Scenario.

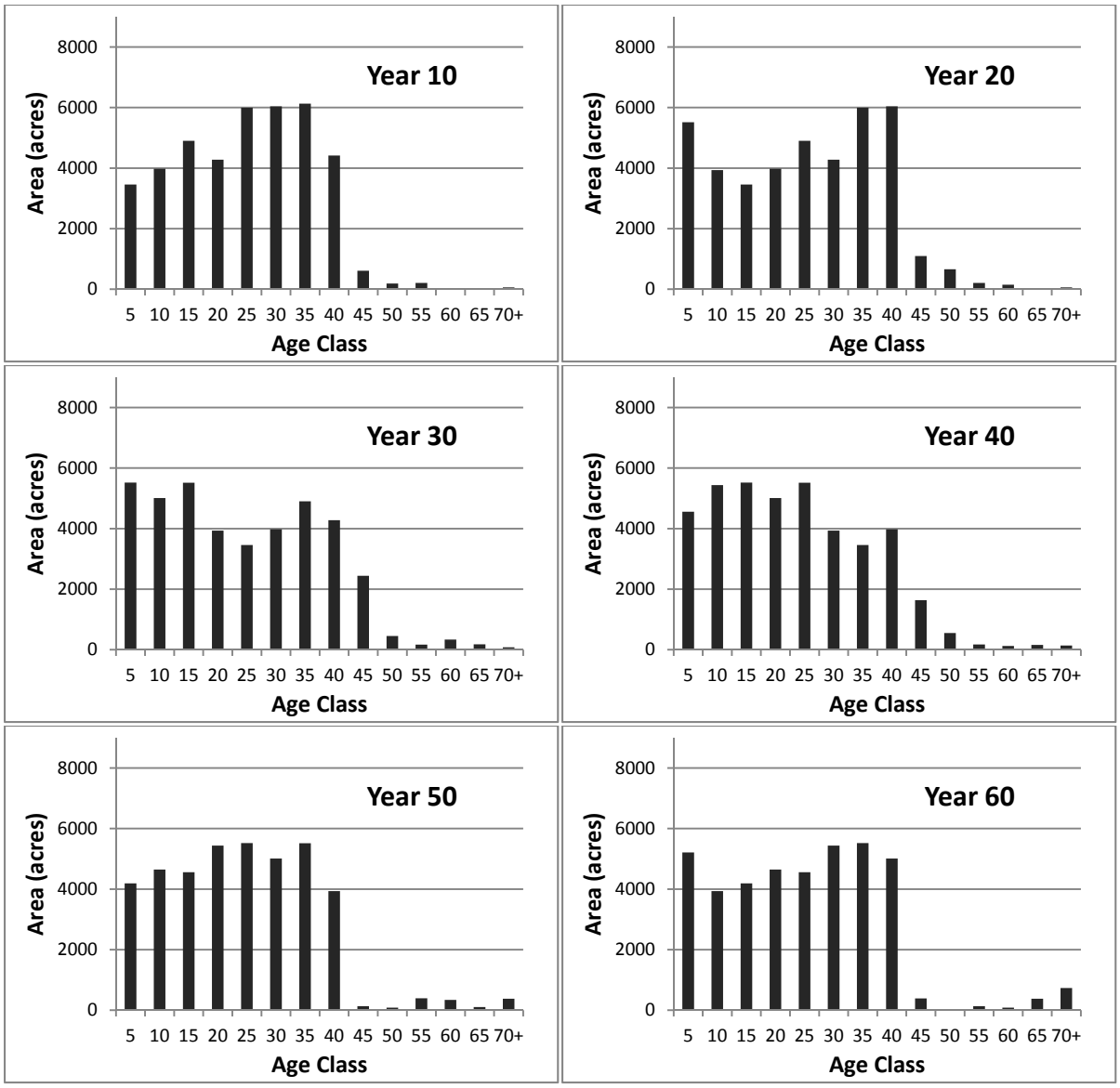

Figure 10. Projected age class distributions for the aspen cover type at 10-year intervals for the Aspen40, Area-and-Revenue Ranges Scenario.

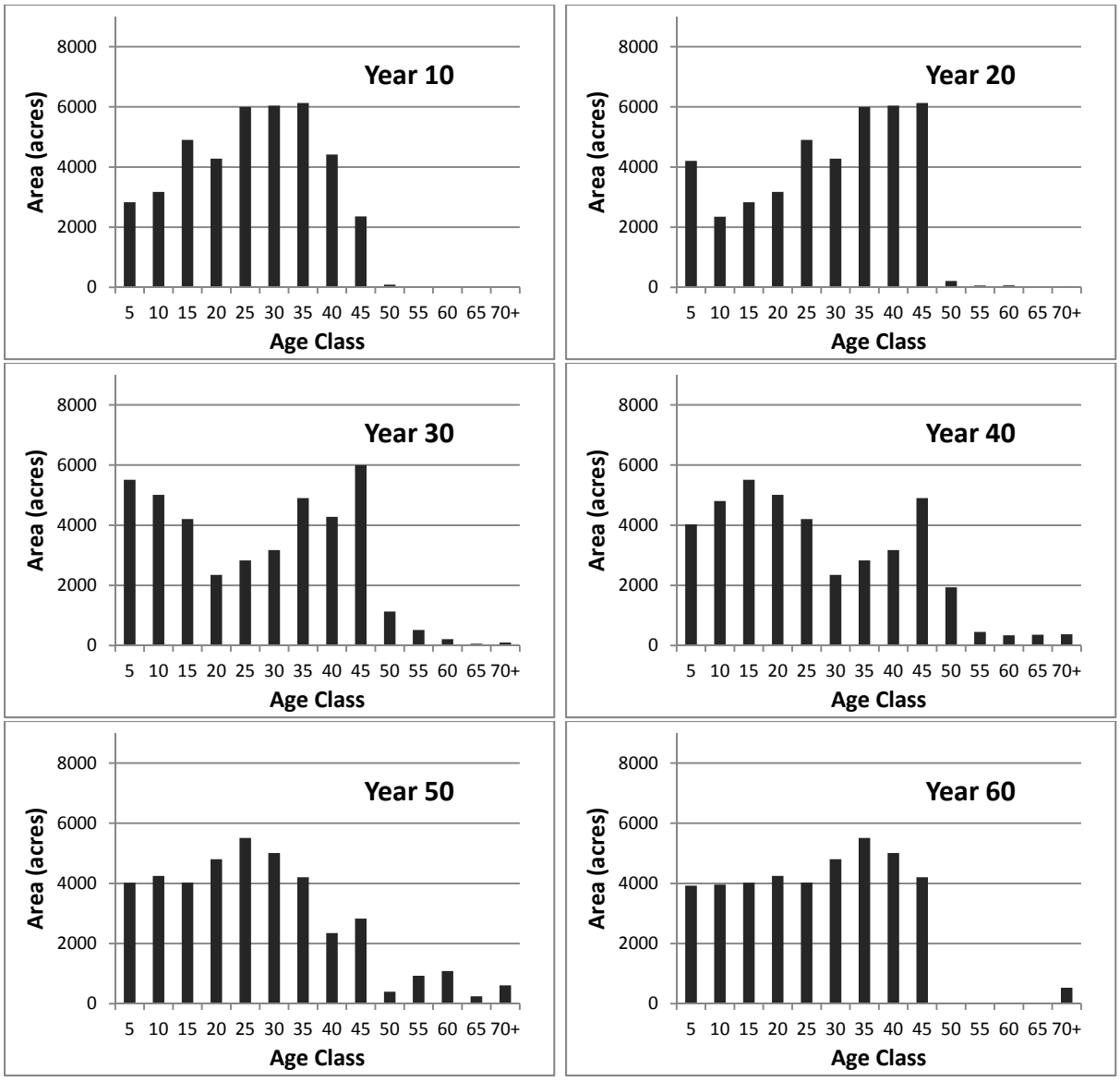

Figure 11. Projected age class distributions for the aspen cover type at 10-year intervals for the Aspen45, Area-and-Revenue Ranges Scenario.

Age Class Distributions of the Oak Cover Type

As described earlier in an overview of the CWC forest management situation, stands in the oak cover type are currently relatively old (Figure 3), and oak is CWC's second largest cover type in terms of area. For these reasons, it has been the cover type recognized by the county as the likely top candidate for increased harvesting to help offset an expected temporary 5- to 20-year decrease in harvesting in the aspen cover type. However, moving the oak type to a more regulated condition is also a management objective, so CWC would like to spread out oak harvesting over a number of 5-year periods. The "Area-and-Revenue Control" scenarios assumed harvest levels for oak could not exceed 650 acres per year. Figure 12 shows the resulting age class distribution for the "Age 40, Area-and-Revenue Control" scenario at 20-year

intervals over the entire planning horizon. Of concern is the general lack of area in a consecutive set of eleven 5-year age classes that "ages" (moves to older age classes) over the planning horizon. Of note is the large spike of acres that moves to the age 125+ age class. For the year 80 age class distribution (Figure 12) an approximate 650 acres of age 0 to 5 oak is not present because nearly all of the oak stands initially present in the inventory are too old to harvest after approximately 75 years. The year 100 graph shows little oak regeneration for 15 years with a substantial area in the oldest oak age class (too old to harvest).

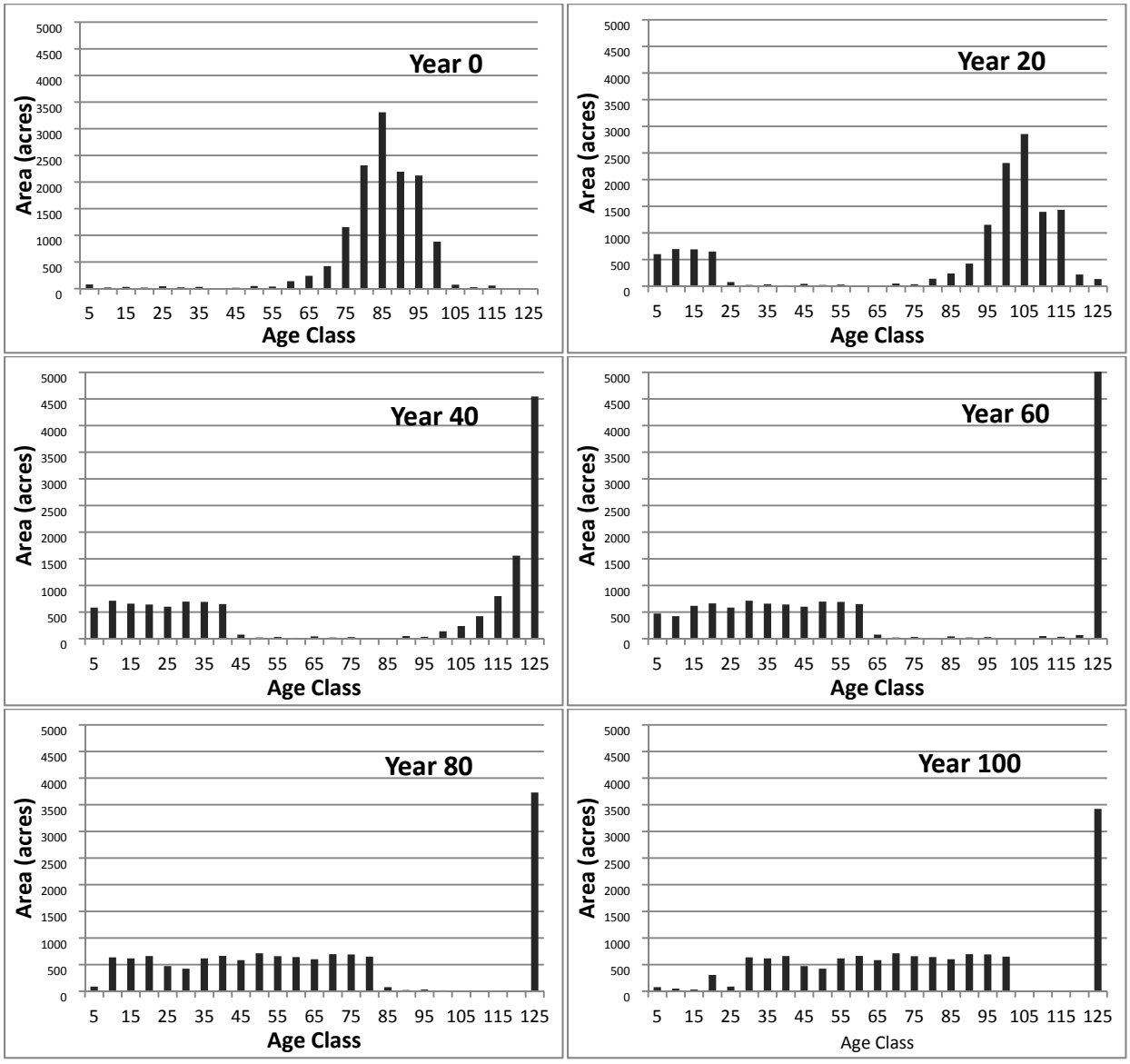

Figure 12. Projected age class distributions for the oak cover type at 20-year intervals for the Aspen40, Area-and-Revenue Control Scenario.

Figure 13 shows graphs of the age class distribution for stands in the oak cover type for the "Age 40, Area-and-Revenue Ranges" scenario. This scenario allowed harvesting of the oak type to be as large as 2,000 acres/period yet sets as a target to regenerate at least 300 acres of oak in every

period. As can be seen in the year 20 graph (Figure 13) a substantial area of oak is harvested and regenerated within the first 20 years. But as the graphs show, this larger area will age and become older oak near the end of the planning horizon. Nearly all of the 125+ oak is harvested over the planning horizon under this scenario. The analyses generally suggest that the oak type, with its initial age class distribution having most acres in a narrow range of older stand ages, will generally be difficult to impossible to fully regulate over a single rotation. By the end of the planning horizon, the "Age 40, Area and Revenue Ranges" scenario has moved the oak cover type closer to a fully regulated condition, with at least some acres present in all age classes less than age 105.

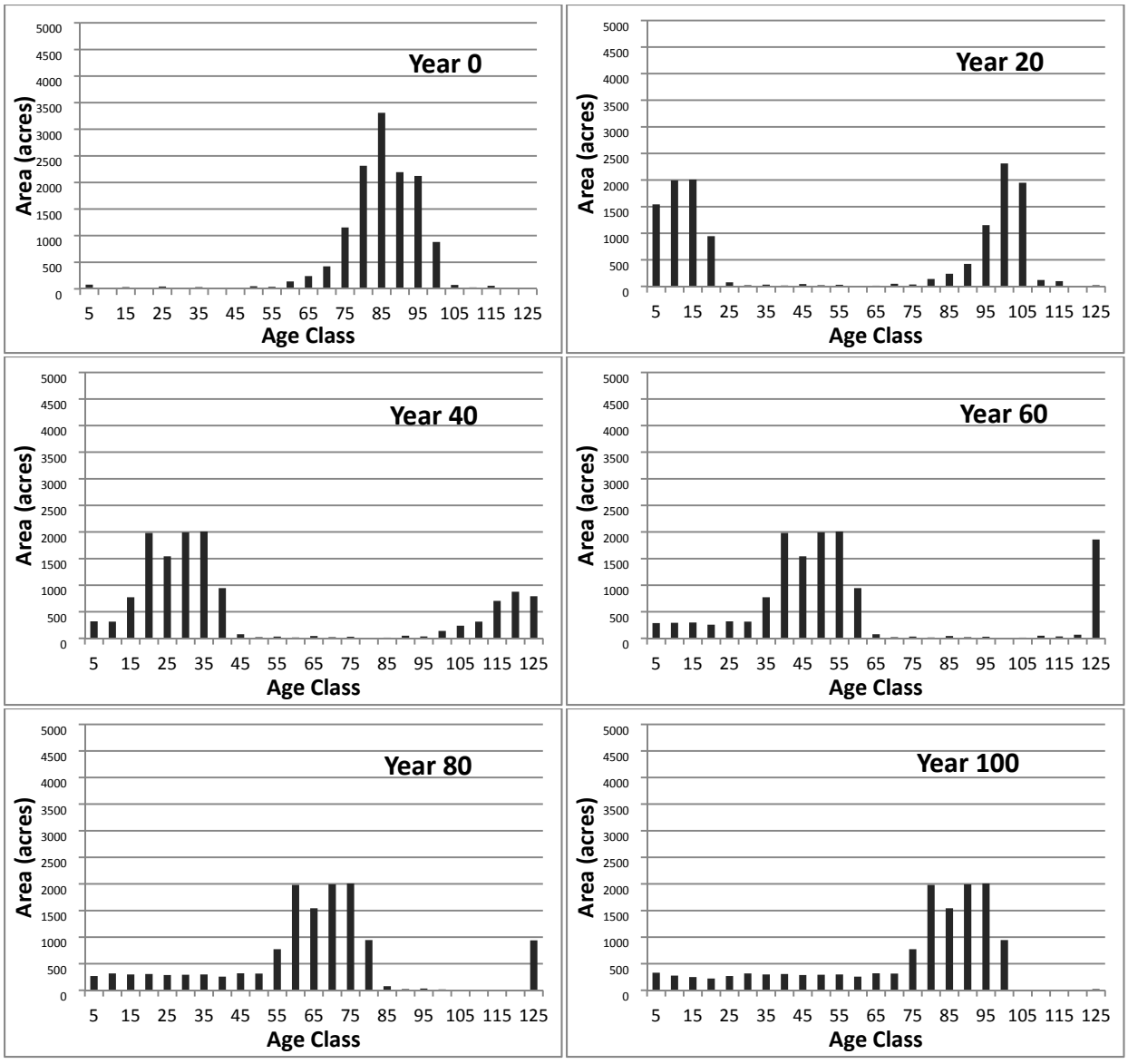

Figure 13. Projected age class distributions for the oak cover type at 20-year intervals for the Aspen40, Area-and-Revenue Ranges Scenario.

Coordinating Harvest Timings Across Cover Types

A major "objective" with all scenarios, other than the benchmark scenarios, was to generate a relatively stable flow of revenue over time. Basically, with the aspen cover type having more young aspen stands at the start of the planning horizon, more harvesting is needed in early periods in cover types other than the aspen cover type. Figure 14 compares the area of 0 to 5 age stands in the aspen cover type to the total area of 0 to 5 age stands at 5-year intervals throughout the planning horizon for the "Age 50, Area-and-Revenue Control Scenario." The year 0 values show that approximately 5,000 of the 6,000 acres regeneration harvested in the last 5 years have occurred in the aspen cover type. Long term, for this scenario, the aspen harvest level is pretty much a consistent 4,000 acres as would be characteristic of a regulated condition of the aspen cover type based on a 50-year rotation. Scheduled harvesting is such that for a 15-year period starting in year 6, the total area of age 0 to 5 stands, over all cover types, is not even 4,000 acres. Basically, as evident earlier in Figure 5, harvest revenues fall short of the targeted $600,000/yr level during this 15-year period for the "Aspen 50, Area-and-Revenue Control Scenario." In later periods, the amount of harvesting in the aspen cover type is relatively high compared to the total area and quite similar to the relationship shown in the year 0 comparison that represents regeneration harvesting over the last five years.

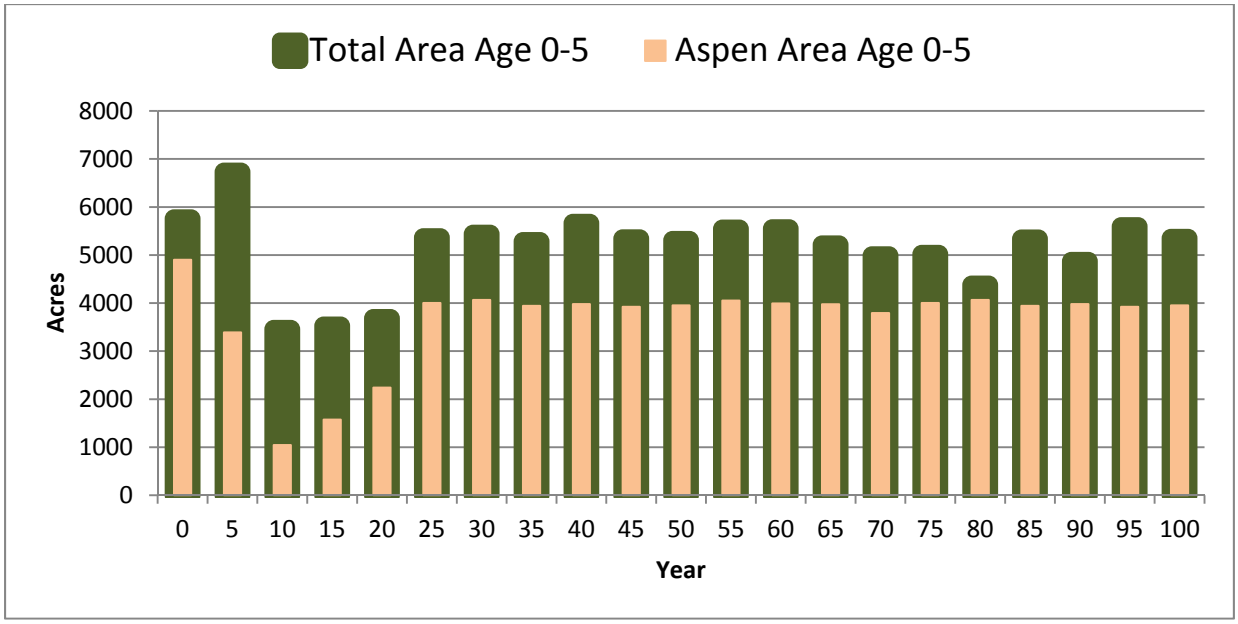

Figure 14. For the "Aspen 50, Area-and-Revenue Control Scenario," a comparison over time of the area in the age 0 to 5 age class in the aspen cover type to the total area in the 0- to 5-year age class over all cover types. The area in the 0 to 5 age class represents area regeneration harvested in the last 5 years. Year 0 represents the condition of the forest at the start of the planning horizon.

Figure 15 compares the area of 0 to 5 age stands in the aspen cover type to the total area of 0 to 5 age stands at 5-year intervals throughout the planning horizon for the "Age 40, Area-and-Revenue Control Scenario." Comparing this figure to Figure 14, substantially more of the aspen cover type can be harvested in early periods with enough harvestable stands in other cover types to reach the timber revenue targets in the early periods when they could not be met when a 50-year minimum rotation is assumed.

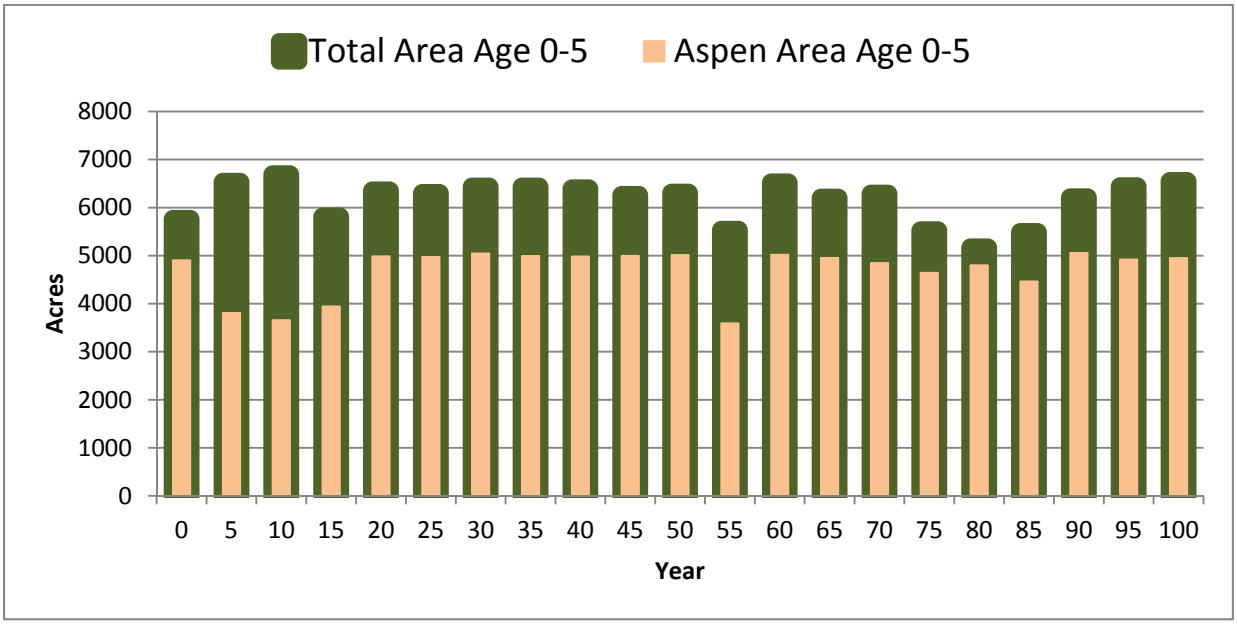

Figure 15. For the "Aspen 40 Area-and-Revenue Control Scenario," a comparison over time of the area in the age 0 to 5 age class in the aspen cover type to the total area in the 0 to 5-year age class over all cover types. The area in the 0 to 5 age class represents area regeneration harvested in the last 5 years. Year 0 represents the condition of the forest at the start of the planning horizon.

Figure 16 compares the area of 0-5 age stands in the aspen cover type to the total area of 0 to 5 age stands at 5-year intervals throughout the planning horizon for the "Age 40 Area and Revenue Ranges Scenario." Compared to the two scenarios described above, harvest levels for the other cover types are somewhat higher in early periods because the harvest areas are allowed to fluctuate more over time. Long term (later periods), the total area regeneration harvested is dominated by the aspen cover type, making up approximately 5/6 of the area regeneration harvested each period. Part of the reason it is so dominant relates to its younger rotation age, with stands regeneration harvested once every 40 to50 years. Oak the second largest cover type, has only 1/3 the area (Figure 1) of the aspen type and oak stands are regeneration harvested only once every 100 years.

Product Mixes

In terms of product values of the timber harvested, aspen product values are not nearly as dominating as is the acreage of the aspen type harvested. A major reason for this is that stands in the aspen cover type are mixed species stands with roughly 1/3 of the volume in species other than aspen. Figure 17 shows the estimated mix of products harvested over time for the "Age 40 Area and Revenue Range Scenario." This scenario is generally representative of all scenarios in terms of product mix, especially for later periods in the planning horizon where aspen is well over half of the total product value. A few other results to note that are not all that surprising. First, although oak makes up a substantial component of the product mix short term, its revenue flows are generally short term. Oak stands are also mixed containing substantial volumes of both aspen and hardwood pulp. Red pine logs make up a substantial portion of product value, with its proportion generally increasing over time. Red pine logs are valuable and overall growth rates

for red pine are substantially higher than those of any other species. CWC will benefit substantially from past investments in red pine reforestation.

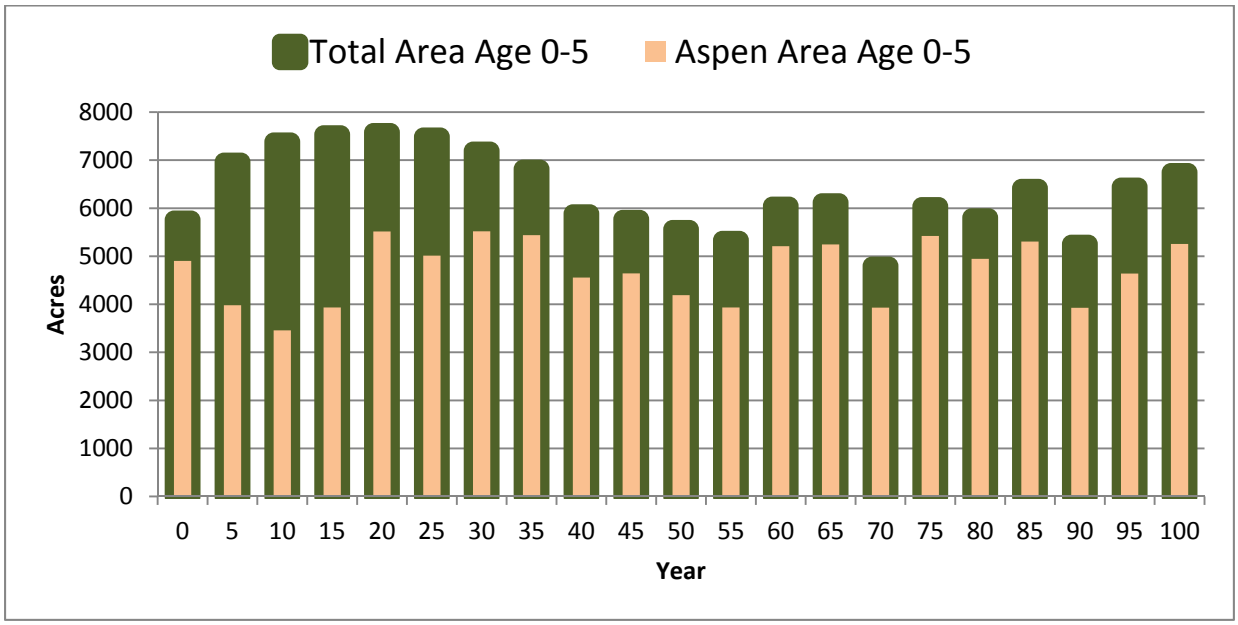

Figure 16. For the "Aspen 40, Area-and-Revenue Ranges Scenario," a comparison over time of the area in the 0 to 5 age class in the aspen cover type to the total area in the 0- to 5-year age class over all cover types. The area in the 0 to 5 age class represents area regeneration harvested in the last 5 years. Year 0 represents the condition of the forest at the start of the planning horizon.

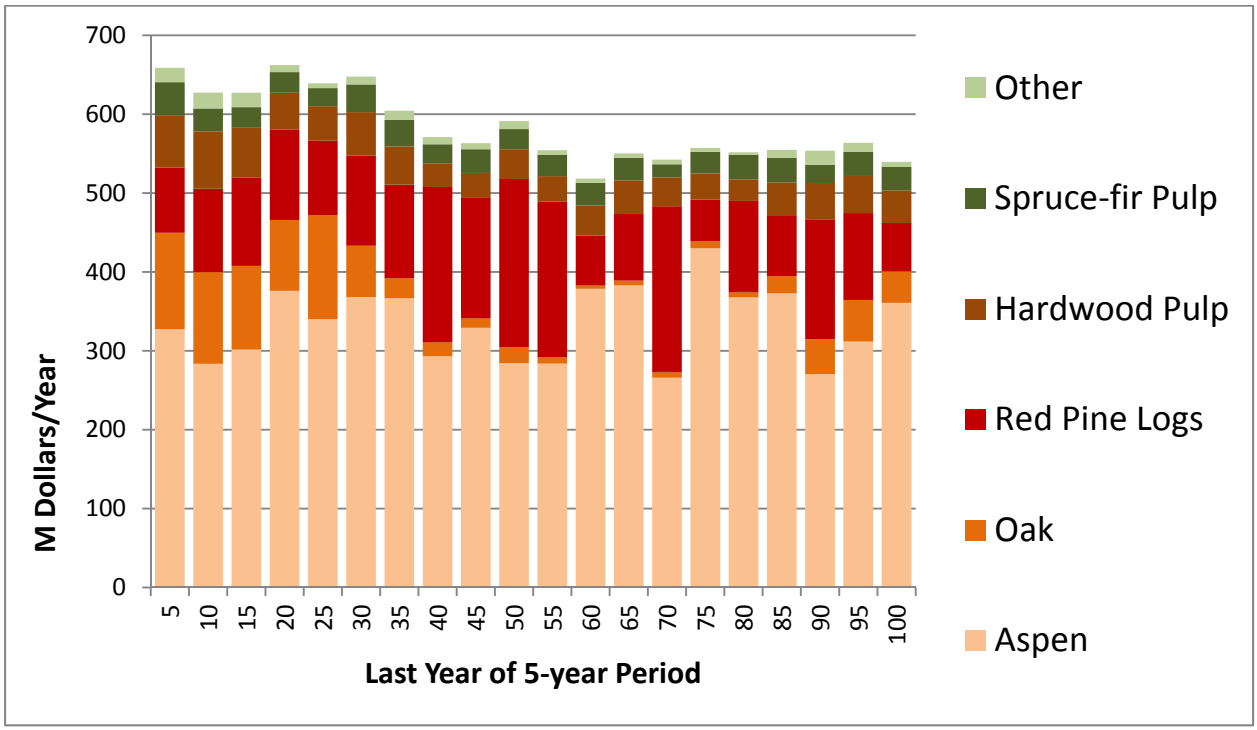

Figure 17. For the "Aspen 40, Area-and-Revenue Ranges Scenario," a breakdown by 5-year planning period of the timber harvest revenue generated by major tree-species product groups.

Another facet to note from Figure 17 is the relative low value of the "Other" product category. These other products like tamarack and lowland hardwoods had low stumpage prices and although the model tended to schedule such stands for harvest, the importance of harvesting these stands for achieving revenue targets is relatively low.

Discussion

Overall, assuming the relatively low timber stumpage prices experienced in the last few years continue, it will be a challenge for the CWC Land Department to sustain timber revenues over the next 20 years or so. The extent of the problem clearly depends heavily on the minimum rotation age assumed for the aspen forest cover type. A younger minimum rotation age helps shorten the time until more aspen stands reach financial maturity.

Also of importance for sustaining revenues will be the potential to harvest heavily in the oak forest cover type. The oak cover type has had minimal harvesting over the last 60 years, and as a result, there are relatively few young oak stands today. The red pine cover type is also important, more important than its relatively small area (approximately 2,800 acres) might suggest. Growth rates for red pine are generally double that of aspen as are current red pine saw log prices.

The applications clearly demonstrate how linear programming can help foresters coordinate management across forest cover types, focusing on total outputs from the forest as a whole. Linear programming is also especially conducive for recognizing the mixed species nature of individual stands. However, given the age of the county's current forest inventory, it was not possible to go into detail concerning variations in tree species mix within each cover type. Future inventory updates will likely help substantially in that regard. Inventory updates will also help lend more insight regarding growth rates for aspen and the potential for shorter aspen rotation lengths. Perhaps only temporary reductions in rotation lengths are desirable to help get past the expected temporary decline in harvest area for the aspen cover type.

Relaxing area control and revenue flow constraints to allow relatively small variation in flows over time has the potential to help reduce costs of even flow constraints from approximately $2.2 million to $1.4 million. These estimates are based on the increases in revenue estimates for the two scenarios that relaxed the forest regulation constraints.

Future analyses should correct for an approximate 500 acres of reserved acres that were considered harvestable in all analyses. Future analyses might look closer at the estimated administration cost of timber sales, especially for small stands. Administration costs were assumed to be approximately $20 for regeneration harvests and $40 per acre for partial harvests, with minimal fixed costs for stand entry. It was assumed that small stands could be blocked into sales, with substantial staff time available to cover most sale administration costs. All of these elements have minimal impact on overall results from a strategic standpoint, and would generally impact each scenario in much the same way. However, it is important to recognize these shortcomings when considering operational aspects of the results. Modeling results are detailed, with it relatively easy to link the management schedules to the existing GIS. County foresters have developed maps and examined the scheduling results in stand-level detail, noting relatively

higher than current harvest schedules for cover types other than aspen. This shift, as noted earlier, is a relatively short-term shift, in an effort to overcome the age class imbalance in the aspen forest cover type. Clearly, the detail and mapping capabilities can help foresters in developing operations to implement the county's forest management plan.

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